**CHEMISTRY 103 – Help Sheet #8**

**Gases (Part II)**

*Do the topics appropriate for your course*

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[https://clc.chem.wisc.edu](https://clc.chem.wisc.edu) (Resource page)

**Nuggets:** Partial Pressure; Kinetic Energy; Velocity; Relative Rates of Gases; Diffusion/effusion; Parts per million; Kinetic Theory of Gases; Gas Equations: Summary

**PARTIAL PRESSURES:** The pressure from one gas in a mixture of gases.

<table>
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<tr>
<th>P&lt;sub&gt;total&lt;/sub&gt; = P&lt;sub&gt;1&lt;/sub&gt; + P&lt;sub&gt;2&lt;/sub&gt; + ...</th>
<th>( \chi_1 = \frac{n_1}{n_{total}} = \frac{P_1}{P_{total}} )</th>
<th>P&lt;sub&gt;1&lt;/sub&gt; = ( \chi_1 P_{total} )</th>
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<tr>
<td>where P&lt;sub&gt;1&lt;/sub&gt;, P&lt;sub&gt;2&lt;/sub&gt;, etc., are the individual gas pressures; Dalton’s Law</td>
<td>( \chi_1 ) = mol fraction gas 1; ( \chi ) is mol% in decimal form; ( n_{total} = n_1 + n_2 + ... )</td>
<td>this means if 30% of the moles of a gas mixture are Gas A (i.e., ( \chi_1 = 0.30 )), then 30% of the total pressure comes from Gas A</td>
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<td>( \sum \chi_i = 1.00 )</td>
<td>P&lt;sub&gt;1&lt;/sub&gt;V = n&lt;sub&gt;1&lt;/sub&gt;RT</td>
<td>P&lt;sub&gt;total&lt;/sub&gt;V = n&lt;sub&gt;total&lt;/sub&gt;RT</td>
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<tr>
<td>sum of the mole fractions totals 1.00 (i.e., 100%)</td>
<td>applying the Ideal Gas Law to one gas in a mixture of gases</td>
<td>applying the Ideal Gas Law to the sum of all gases in a mixture of gases</td>
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**Example 1:** a. If a glass bulb contains 110.0 g CO<sub>2</sub> and 140.0 g CO with a total pressure of 6.60atm, what is the partial pressure of CO<sub>2</sub>?

**Answer 1:** a. P<sub>CO2</sub> = 2.20atm  b. P<sub>CO</sub> = 4.40atm  \{use P<sub>1</sub> = \( \chi_1 P_{total} \); find mol CO<sub>2</sub> and mol CO;\}

\[
110.0 \text{g CO}_2 \left( \frac{1 \text{mol CO}_2}{44.0 \text{g CO}_2} \right) = 2.50 \text{mol CO}_2; \quad 140.0 \text{g CO} \left( \frac{1 \text{mol CO}}{28.0 \text{g CO}} \right) = 5.00 \text{mol CO}; \quad \text{now find mol fraction, } \chi, \text{ for both CO}_2 \text{ and CO;}
\]

\[
\chi_{CO_2} = \frac{\text{mol CO}_2}{\text{mol CO}_2 + \text{mol CO}} = \frac{2.50}{2.50 + 5.00} = 0.333; \quad \chi_{CO} = \frac{\text{mol CO}}{\text{mol CO}_2 + \text{mol CO}} = \frac{5.00}{2.50 + 5.00} = 0.667;
\]

\[
\text{now find partial pressures: } P_{CO_2} = \chi_{CO_2} P_{total}; \quad P_{CO} = (0.333)(6.60 \text{atm}) = 2.20 \text{atm}; \text{ (a way to think about this: 0.333 or } \frac{1}{3} \text{ of the molecules are CO}_2 \text{ therefore 0.333 or } \frac{1}{3} \text{ of the pressure is due to CO}_2); \]

\[
P_{CO} = \chi_{CO} P_{total}; \quad P_{CO} = (0.667)(6.60 \text{atm}) = 4.40 \text{atm}; \text{ (a way to think about this: 0.667 or } \frac{2}{3} \text{ of the molecules are CO therefore 0.667 or } \frac{2}{3} \text{ of the pressure is due to CO); could also have calculated } P_{CO} \text{ from } P_{total} = P_1 + P_2 = P_{CO} + P_{CO_2}; \quad P_{CO} = 6.60 \text{atm} - 2.20 \text{atm} = 4.40 \text{atm}\}

**Example 2:** A 50.0-L steel tank contains He and Ne. The container is at 25.0°C and contains 56.0g He. a. What is the partial pressure of He?

**Answer 2:** a. P<sub>He</sub> = 6.85atm  b. 120.0g Ne  \{use P<sub>1</sub>V = n<sub>1</sub>RT; \ P<sub>He</sub> = \( \frac{n_{He} RT}{V} \); \ n<sub>He</sub> = 56.0g He \left( \frac{1 \text{mol He}}{4.00 \text{g He}} \right) = 14.0 \text{mol He}; \}

\[
T = 25.0 + 273.15 = 298.15 \text{K}; \quad P_{He} = \frac{(14.0 \text{mol})(0.0821 \text{L atm/molK})(298.15 \text{K})}{50.0 \text{L}} = 6.85 \text{atm}; \text{ from Dalton’s Law: } P_{total} = P_{He} + P_{Ne};
\]

\[
P_{Ne} = 9.75 - 6.85 = 2.90 \text{atm}; \text{ use } P_{Ne}V = n_{Ne}RT \text{ to find } n_{Ne}; \quad n_{Ne} = \frac{(2.90 \text{atm})(50.0 \text{L})}{(0.0821 \text{L atm/molK})(298.15 \text{K})} = 5.924 \text{mol Ne};
\]

\[
5.924 \text{mol Ne} \left( \frac{20.18 \text{g Ne}}{1 \text{mol Ne}} \right) = 119.5 \text{g Ne};
\]

**Example 3:** When a hydrocarbon gas is collected in a 5.0-L vessel at 35.0°C over water the pressure recorded was 825torr. The vapor pressure of water at 35.0°C is 42.2torr. How many moles of the hydrocarbon were present?

**Answer 3:** \( \text{P}_{\text{hydrocarbon}} = 0.203 \text{mol} \)  \{P<sub>T</sub> = P<sub>H2O</sub> + P<sub>hydrocarbon</sub>; 825torr = 42.2 + P<sub>hydrocarbon</sub>; P<sub>hydrocarbon</sub> = 782.8torr; use P<sub>1</sub>V = n<sub>1</sub>RT and solve for n<sub>hydrocarbon</sub>; \}

\[
n_{\text{hydrocarbon}} = \frac{P_{\text{hydrocarbon}} V}{RT}; \quad n_{\text{hydrocarbon}} = \frac{(782.8 \text{torr})(1 \text{Latm}/760 \text{torr})(5.0 \text{L})}{(0.0821 \text{Latm/molK})(35.0 + 273.15 \text{K})} = 0.203 \text{mol hydrocarbon};
\]
Example 4: (More challenging question) 10.0g N₂(g) reacts with 15.0g O₂ in the reaction below. Assuming the reaction goes to completion, the temperature was 55.0°C, and the volume of the container was 2.0L, what are the P_N₂, P_O₂, P_N₂O₅, and P_total at the end of the reaction?

\[ 2 \text{N}_2(\text{g}) + 5 \text{O}_2(\text{g}) \rightarrow 2 \text{N}_2\text{O}_5(\text{g}) \]

Answer 4: P_N₂ = 2.28atm; P_N₂O₅ = 2.53atm; P_O₂ = 0atm; P_total = 4.81atm

[Limiting reagent (LR) problem since 2 reactant quantities given; need to find how many mol of each chemical are left over at the end of the reaction; do \( g_A \rightarrow \text{mol}_B \) two times to determine mol \( \text{N}_2\text{O}_5 \) produced and which reactant is the LR;

\[
10.0 \text{g N}_2 \left( \frac{1 \text{mol N}_2}{28.0 \text{g N}_2} \right) = 0.3572 \text{mol} \text{N}_2;\quad 15.0 \text{g O}_2 \left( \frac{1 \text{mol O}_2}{32.0 \text{g O}_2} \right) = 0.4688 \text{mol} \text{O}_2;\quad \text{LR = N}_2 \]

The smallest quantity of \( \text{N}_2\text{O}_5 \) can be produced: 0.1875mol \( \text{N}_2\text{O}_5 \) is produced; \( \text{O}_2 \) is the LR since it produced the smaller amount of \( \text{N}_2\text{O}_5 \) and therefore 0 mol of \( \text{O}_2 \) are left over at the end of the reaction; find out how many moles of excess reactant, \( \text{N}_2 \), is left over at the end of the reaction; left over = starting amount – amount used;

find starting amount \( \text{N}_2 \) in mol: \( 10.0 \text{g N}_2 \left( \frac{1 \text{mol N}_2}{28.0 \text{g N}_2} \right) = 0.3571 \text{mol} \text{N}_2;\)

find amount \( \text{N}_2 \) used in mol: LR \( \rightarrow \) EX: \( 15.0 \text{g O}_2 \left( \frac{1 \text{mol O}_2}{32.0 \text{g O}_2} \right) \left( \frac{2 \text{mol N}_2}{5 \text{mol O}_2} \right) = 0.1875 \text{mol} \text{N}_2 \) used;

left over = 0.3571 – 0.1875 = 0.1696mol \text{N}_2;

use \( P_1V = n_1RT \) and solve for \( P_1 \) for each gas; \( P \text{N}_2 = \frac{n_2RT}{V}; \)

\[
P \text{N}_2 = \frac{(0.1696 \text{mol})(0.0821 \text{Latm/molK})(55.0 + 273.15 \text{K})}{(2.0 \text{L})} = 2.2846 \text{atm} \text{N}_2;\]

\[
P \text{N}_2\text{O}_5 = \frac{(0.1875 \text{mol})(0.0821 \text{Latm/molK})(55.0 + 273.15 \text{K})}{(2.0 \text{L})} = 2.5257 \text{atm} \text{N}_2\text{O}_5;\]

\[
P \text{O}_2 = \frac{(0 \text{mol})(0.0821 \text{Latm/molK})(55.0 + 273.15 \text{K})}{(2.0 \text{L})} = 0 \text{atm} \text{O}_2; \quad P \text{total} = P \text{N}_2 + P \text{O}_2 + P \text{N}_2\text{O}_5 = 2.2846 + 0 + 2.5257 = 4.8103 \text{atm};\]

VELOcity

\[ \text{KE} = \frac{1}{2} m v^2 \rightarrow \text{for a single molecule (KE = kinetic energy)}; \]

for one mole of molecules this becomes: \( \text{KE}_{\text{average}} = \bar{\text{KE}} = \frac{1}{2} \overline{M v^2} \)

where \( \overline{\text{KE}} \) (J) is average KE; \( M \) is molar mass of the gas; \( \overline{v^2} \) is the mean of the squared velocity; \( \overline{\text{KE}} = \frac{3}{2} R T \) and therefore \( \text{KE} \propto T \); the KE calculated using \( \frac{3}{2} R T \) is for 1 mol of gas

Now set the two different \( \overline{\text{KE}} \) equations equal to one another: \( \frac{1}{2} M \overline{v^2} = \frac{3}{2} R T \)

and solve for root mean square velocity, \( \overline{v^2}; \quad \sqrt{\overline{v^2}} = \overline{v_{\text{root mean square}}} = \overline{v_{\text{rms}}} = \sqrt{ \frac{3RT}{M} } \)

where \( M \) = molar mass (kg/mol not g/mol); \( R = 8.314 \text{J/(molK)} \); \( T \) in K; \( v_{\text{rms}} \) in m/s

The most probable gas velocity, \( v_{\text{most probable}} = v_{\text{peak}} \), occurs at the peak, the average speed, \( v_{\text{average}} = \overline{V} \), appears at a different location, and the root mean square velocity \( (v_{\text{rms}}) \) appears at a third location on the distribution of molecular velocities versus probability.
Probability versus Molecular Speed at Different $T$ or with Different Mass

Comparing the molecular speed distribution of one gas at two temperatures. Note how the curve peak shifts to a faster speed as the temperature increases.

**Example 5:** If $\text{CO}_2(\text{g})$ is at 58.5°C, what is the root mean square velocity of the $\text{CO}_2$ molecules?

**Answer 5:** $4.34 \times 10^2 \text{ m/s}$

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}; \quad v_{\text{rms}} = \sqrt{\frac{3(8.314)(58.5 + 273.15)}{(44.01 \text{ g/mol})(1 \text{ kg/1000 g})}}; \quad v_{\text{rms}} = \frac{8272.0}{0.04401}; \quad v_{\text{rms}} = \frac{8272.0}{0.04401} = 4.335 \times 10^2 \text{ m/s}$$

**Example 6:** If $\text{Ar}(\text{g})$ atoms are moving at 509 m/s what is the average $T$ in K of these atoms?

**Answer 6:** 415K

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}; \quad 509.0 = \sqrt{\frac{3(8.314)(T)}{(39.95 \text{ g/mol})(1 \text{ kg/1000 g})}}; \quad (509)^2 = \left(\frac{24.942(T)}{0.03995}\right)^2; \quad 259,081 = \frac{24.942(T)}{0.03995}; \quad 259,081 = 624.33T; \quad T = 414.97K$$

**Example 7:** Place the following gases all at the same $T$ in order from slowest root mean square velocity to fastest root mean square velocity. $\text{Ar}$, $\text{CO}_2$, $\text{Ne}$, $\text{O}_2$

**Answer 7:** $\text{CO}_2 < \text{Ar} < \text{O}_2 < \text{Ne}$

since **larger molecules move slower than smaller molecules** at the same $T$, place them in order by molar mass: $\text{CO}_2$ (44 g/mol) < $\text{Ar}$ (40 g/mol) < $\text{O}_2$ (32 g/mol) < $\text{Ne}$ (20.2 g/mol)

**Diffusion:** the mixing of two gases.

$$\frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{M_2}{M_1}} \quad \text{and} \quad \frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{T_1}{T_2}} \quad \text{and} \quad \frac{M_1}{M_2} = \frac{T_1}{T_2}$$

**rate can be velocity, rate of diffusion; $T$ in K; $M$ in kg/mol**

**Parts per million:** The number of molecules per 1 million molecules

Convert percent to parts per million (ppm): Change % to decimal form and multiply by $\left(\frac{1 \times 10^6}{1 \times 10^6}\right)$

**Example 1:** a. If methane, $\text{CH}_4$, is 0.0000722% in the atmosphere, what is the amount of methane in ppm?

**Answer 1:** 0.722 ppm

Step 1: Convert % to decimal: $0.0000722\% / 100 = 0.000000722$

Step 2: Multiply by $\frac{1 \times 10^6}{1 \times 10^6}; \quad 0.00000072 \cdot \frac{1 \times 10^6}{1 \times 10^6} = 0.72 \text{ parts one million} = 0.72 \text{ parts per million} = 0.72 \text{ ppm}$

(note that $1 \times 10^6 = 1$ million so the bottom $1 \times 10^6$ is replaced with “one million”)}

*take home messages from above graphs:*

1. Smaller gas molecules travel faster than heavier ones at same $T$;
2. Same gas molecules travel faster at higher $T$
Kinetic-Molecular Theory
1. A gas is composed of molecules that are small compared to the distances between them; most of a gas volume is empty space.
2. Gas molecules are in constant random motion moving at varying speeds.
3. The attractive/repulsive forces between gas molecules are minimal.
4. Molecular collisions and collisions with the container walls occur without loss of E (elastic collisions), and the collisions with the container create pressure.

Gas Equations: Summary

<table>
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<th>Gas Laws</th>
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<tbody>
<tr>
<td>( P_1V_1 = P_2V_2 ) (( P \propto \frac{1}{V} ))</td>
</tr>
<tr>
<td>( PV = nRT )</td>
</tr>
<tr>
<td>STP: ( P = 1\text{atm}; T = 0^\circ \text{C}; 1\text{mol gas} = 22.4\text{L at STP} )</td>
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Stoichiometry

- Atoms or molecules A: 1 mol = \( 6.022 \times 10^{23} \)
- Molar mass: moles A/L
- Molar mass: moles B/L
- Chemical Reaction or Chemical Formula
- M = molA/L, M = molB/L
- moles A
- moles B
- atoms or molecules B: 1 mol = \( 6.022 \times 10^{23} \)
- grams A:
- grams B:
- \( 22.4 \text{ L} = 1 \text{ mol at STP or} \ PV = nRT \)
- \( 22.4 \text{ L} = 1 \text{ mol at STP or} \ PV = nRT \)

Partial Pressure

| \( P_{\text{total}} = P_1 + P_2 + ... \) |
| \( \Sigma X_i = 1.00 \) |
| \( \chi_i = \frac{n_i}{n_{\text{total}}} = \frac{P_i}{P_{\text{total}}} \) |
| \( P_{\text{total}}V = n_{\text{total}}RT \) |
| \( P_1V = n_1RT \) |
| \( P_{\text{total}}V = n_{\text{total}}RT \) |

Kinetic Molecular Theory (Velocity)

| KE_{\text{average}} = KE = \frac{1}{2} MV^2 |
| KE = \frac{3}{2} RT |
| v_{\text{rms}} = \sqrt{\frac{3RT}{M}} |
| \frac{\text{rate}_1}{\text{rate}_2} = \frac{M_2}{M_1} |
| \frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{T_1}{T_2}} \text{ (if covered)} |
| \frac{M_1}{M_2} = \frac{T_1}{T_2} \text{ (if covered)} |

Molecular Speed Distribution at Two Temperatures

Molecular Speed Distribution with Different Masses
1. A container has 6.0mol Ne, 4.0mol N₂, and 5.0mol NH₃ with a total pressure of 1.5atm. What is the partial pressure of NH₃?

2. A sample of the atmosphere contained 120.12 g of nitrogen gas (N₂) and 38.72 g of oxygen gas (O₂). What is the partial pressure of N₂ and O₂ when the atmospheric pressure is 730.0 torr?

3. A 2.0-L container at 25°C has both N₂ and O₂ in it. The pressure on the system is determined to be 550torr with the partial pressure due to N₂ being 450torr. How many grams of O₂ are in the flask?

4. A mixture of 2.0mol SO₂(g), 1.0mol H₂O(g), and 3.0mol O₂(g) have a total pressure of 100torr. Which gas has the greatest partial pressure?

5. A 1.85g sample of ammonium nitrate (molar mass = 80.1g/mol) in an evacuated 2.12L flask is heated to 250°C. What are the partial pressures of H₂O(g) and N₂O(g), and the total pressure in the flask at 250°C when the ammonium nitrate has completely decomposed according to the following reaction?
   \[ \text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{N}_2\text{O}(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \]

6. 25.0g N₂(g) reacted with 45.0g O₂(g) to completion and produced N₂O₃(g) in a 5.0L reaction vessel. The temperature was 70.0°C. What is the partial pressure of N₂(g), O₂(g), and N₂O₃(g), and what is the total pressure at the end of the reaction?
   \[ 2\text{N}_2(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{N}_2\text{O}_3(\text{g}) \]

7. The valve between a 5-L tank containing a gas at 9atm and a 10-L tank containing a gas at 6atm is opened. Calculate the final pressure in the tanks after the valve is opened.
   a. 10 atm  
   b. 9 atm  
   c. 8 atm  
   d. 7 atm  
   e. 6 atm

8. If four 1-L flasks contain He, Ne, O₂, and CO₂ at the same T and P, which has the greatest average KE?
   a. He  
   b. Ne  
   c. O₂  
   d. CO₂  
   e. All have same KE

9. What is the total kinetic energy in Joules for 2.0L of He at 175°C and 2.0atm?

10. Order the following gases for decreasing rate of velocity: CO₂, N₂, O₂, Ar, H₂O (all gases are at the same T)
    a. CO₂ > N₂ > O₂ > Ar > H₂O  
    b. H₂O > N₂ > O₂ > Ar > CO₂  
    c. CO₂ > Ar > O₂ > N₂ > H₂O  
    d. Ar > N₂ > O₂ > H₂O > CO₂  
    e. CO₂ > H₂O > N₂ > O₂ > Ar

11. What is the root mean square velocity of methane, CH₄(g), at 25.0°C.
    a. 682 m/s  
    b. 1.46 x 10⁻³ m/s  
    c. 55.6 m/s  
    d. 4.64 x 10⁵ m/s  
    e. none of the above

12. If the root mean square velocity of NH₃ molecules is found to be 510. m/s, what is the temperature in K?

13. If the total kinetic energy of 1.50mol of CO₂ gas was 7.50kJ, what is the temperature of the CO₂?
14. If the diffusion rate of CO\(_2\) was measured as 245 m/s and another gas under the same conditions was measured to have a diffusion rate of 406 m/s what is the unknown gas?
   a. O\(_2\)  b. N\(_2\)  c. SO\(_2\)  d. Ne  e. CH\(_4\)

15. At what temperature would CO\(_2\) molecules have a velocity equal to that of H\(_2\) gas at 20.0 °C?

16. a. In 1920 the CO\(_2\)(g) concentration in the atmosphere was 0.0303% by volume in the atmosphere. What is this amount of carbon dioxide in ppm?
   b. How many molecules of carbon dioxide monoxide would be in 1.0 L of air at -56.5°C and 54.2 torr? (These are the approximate temperature and pressure at 60,000 feet above sea level.)
   c. Currently (2018), there is 407 ppm of CO\(_2\) molecules in the atmosphere. What percent increase does this represent from 1920 CO\(_2\) levels?

17. Four 1-L containers have the following gases: CO\(_2\) CH\(_4\) SO\(_2\) Ar
   If the containers are all at the same temperature and pressure, which gas will have the
   a. highest density? _____
   b. greatest mass? _____
   c. greatest number of molecules? _____
   d. greatest average kinetic energy? _____
   e. greatest number of moles? _____
   f. greatest root mean square velocity? _____
   g. greatest number of atoms? _____

18. Ne is 10 times the mass of H\(_2\). Which of the following statements is true if each gas is placed in a 1-L container?
   I. With one mol of each gas in the container both at 25°C they both have the same kinetic energy.
   II. Ten moles of H\(_2\) would have the same volume as 1 mole of Ne both at STP.
   III. One mole of Ne would exert the same pressure as one mole of H\(_2\) both at 25°C.
   IV. A Ne atom travels 10 times faster than a H\(_2\) molecule both at 25°C.
   V. One liter of Ne has 10 times the density when compared to one liter of H\(_2\) both at STP.

19. A wizard from Hogwarts releases two gases at the same time in a large hall maintained at a temperature of 25.00°C (assume that the ventilation units are off). One gas makes you smile (molar mass = 44.02 g/mol) and is released at Row 1. The other gas makes you frown (molar mass = 171.04 g/mol) and is released at Row 13.
   a. If you are located on Row 7 (equidistant between the two gases) would you be smiling or frowning? Explain. (Hint: no calculation needed for this part)
   b. What Row would the people be smiling and frowning at the same time?
   (Hint: \(\frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{M_2}{M_1}}\) and distance = velocity x time)

ANSWERS

1. c  \(P_{NH_3} = \chi_{NH_3}P_T\) and solve for \(P_{NH_3}\):
   \[\chi_{NH_3} = \frac{\text{mol NH}_3}{\text{mol Total}} = \frac{5.0}{6.0 + 4.0 + 5.0} = 0.33;\]
   \(P_{NH_3} = (0.333)(1.5\text{ atm}) = 0.50\text{ atm}\)
2. 569.3 torr N₂ and 160.7 torr O₂  \{P_i = P_T \chi_i; P_T = 730.0\text{torr}; convert g \rightarrow mol;\}

\[
120.12\text{g N}_2 \left(\frac{1\text{mol N}_2}{28.02\text{g N}_2}\right) = 4.288\text{mol N}_2; \quad 38.72\text{g O}_2 \left(\frac{1\text{mol O}_2}{32.00\text{g O}_2}\right) = 1.210\text{mol O}_2
\]

\[n_T = 1.210 + 4.288 = 5.498\text{mol}; \quad \chi_{N_2} = \frac{4.288}{5.498} = 0.7799; \quad \chi_{O_2} = \frac{1.210}{5.498} = 0.2200;\]

\[P_{N_2} = (730.0)(0.7799) = 569.3\text{torr}; P_{O_2} = (730.0)(0.2200) = 160.7\text{torr}\}

3. 0.34g O₂  \{P_iV = n_iRT; n_{O_2} = \frac{P_{O_2}V}{RT}; find P_{O_2} from P_T = P_{O_2} + P_{N_2}; P_{O_2} = 550-450 = 100\text{torr};\}

\[n_{O_2} = \frac{P_{O_2}V}{RT} = \frac{(100\text{torr})(1\text{atm} / 760\text{torr})(2.0L)}{(0.0821\text{L atm} / \text{mol K})(25 + 273.15\text{K})} = 0.01075\text{mol O}_2; \quad 0.01075\text{mol O}_2 \left(\frac{32.00\text{g O}_2}{1\text{mol O}_2}\right) = 0.3440\text{g O}_2\}

4. O₂(g)  \{since there are more moles of O₂(g), it will have a greater \chi_{O_2} and therefore a great partial pressure\}

5. P_{H_2O} = 0.936\text{atm}; P_{N_2O} = 0.468\text{atm}; P_T = 1.40\text{atm};  \{P_{H_2O}V = n_{H_2O}RT; P_{H_2O} = \frac{n_{H_2O}V}{RT}\};

find mol H₂O:  \[n_{H_2O} = \left(1.85\text{g NH}_4\text{NO}_3\right) \left(\frac{1\text{mol NH}_4\text{NO}_3}{80.1g \text{NH}_4\text{NO}_3}\right) \left(\frac{2\text{mol H}_2\text{O}}{1\text{mol NH}_4\text{NO}_3}\right) = 0.04619\text{mol H}_2\text{O}\]

\[P_{H_2O} = \frac{nRT}{V} = \frac{(0.04619\text{mol})(0.0821\text{L atm} / \text{mol K})(250.0 + 273.15\text{K})}{2.12L} = 0.9358\text{atm H}_2\text{O}\]

find mol N₂O: 0.04619mol H₂O x (1mol N₂O/2mol H₂O) = 0.02310mol N₂O;

\[n_{N_2O} = \frac{nRT}{V} = \frac{(0.02310\text{mol})(0.0821\text{L atm} / \text{mol K})(250.0 + 273.15\text{K})}{2.12L} = 0.4680\text{atm N}_2\text{O}\]

P_{total} = P_{H_2O} + P_{N_2O}; P_{total} = 0.9358 + 0.4680 = 1.4038\text{atm}\}

6. P_{N_2} = 0\text{atm}; P_{O_2} = 0.378\text{atm}; P_{N_2O_3} = 5.03\text{atm}; P_T = 5.41\text{atm}  \{limiting reagent problem since 2 reactant quantities are given; determine how many mol N₂O₃ can be made, which reactant is the LR and how many mol of the excess reactant remains. 25.0g N₂ \left(\frac{1\text{mol N}_2}{28.0g \text{N}_2}\right) \left(\frac{2\text{mol N}_2\text{O}_3}{2\text{mol N}_2}\right) = 0.8929\text{mol N}_2\text{O}_3;\}

\[45.0g O_2 \left(\frac{1\text{mol O}_2}{32.0g O_2}\right) \left(\frac{2\text{mol N}_2\text{O}_3}{3\text{mol O}_2}\right) = 0.9375\text{mol N}_2\text{O}_3; N_2 \text{is the LR since it yielded the smaller amount; O}_2 \text{is the EX; 0.8929mol N}_2\text{O}_3 \text{can be produced; find left over O}_2; \text{left over} = \text{starting amount} – \text{amount used;}\]

find amount O₂ \text{ used} in mol: LR \rightarrow EX: 25.0g N₂ \left(\frac{1\text{mol N}_2}{28.0g \text{N}_2}\right) \left(\frac{3\text{mol O}_2}{2\text{mol N}_2}\right) = 1.3393\text{mol O}_2 \text{used};

\[\text{starting amount O}_2 = 45.0g O_2 \left(\frac{1\text{mol O}_2}{32.0g O_2}\right) = 1.4063\text{mol O}_2; \text{left over O}_2 = 1.4063 – 1.3393 = 0.06701\text{mol O}_2 \text{left over; P}_{N_2} \text{after reaction} = 0.0\text{atm (LR = no N}_2 \text{left)};\]

\[P_{O_2} = \frac{nRT}{V} = \frac{(0.06701\text{mol})(0.0821\text{L atm} / \text{mol K})(70.0 + 273.15\text{K})}{5.0L} = 0.3776\text{atm O}_2;\]

\[P_{N_2O_3} = \frac{nRT}{V} = \frac{(0.8929\text{mol})(0.0821\text{L atm} / \text{mol K})(70.0 + 273.15\text{K})}{5.0L} = 5.0311\text{atm N}_2\text{O}_3\]

\[P_T = P_{N_2} + P_{O_2} + P_{N_2O_3} = 0 + 0.3776 + 5.0311 = 5.4087\text{atm}\}
7. d. {This problem can be done in various ways: an easy way is to run through $P_1V_1 = P_2V_2$ two times; first gas (call it X): $P_1V_1 = P_2V_2$; (9)(5) = $(P_2)(10+5)$; $P_2$ for X = 3.0atm; second gas (call it Y): $P_1V_1 = P_2V_2$; (6)(10) = $(P_2)(10+5)$; $P_2$ for Y = 4.0atm; $P_T = 3.0 + 4.0 = 7.0$atm}

8. e. {since average KE $\propto T$ $\rightarrow$ same T means same average KE}

9. 608J {KE = $\frac{3}{2}RT$ per mol of gas; start by finding mol: PV = nRT;

\[
n = \frac{PV}{RT} = \frac{(2.0\text{atm})(2.0\text{L})}{(0.0821\text{L atm/mol K})(175+273.15\text{K})} = 0.1087\text{mol}; KE = \left(\frac{3}{2}\right)(8.314\text{J/mol K})(175+273.15\text{K})(0.1087\text{mol}) = 607.5\text{J}
\]

10. b. {heavier molecules move slower; find the masses: CO$_2$ (44g/mol), N$_2$ (28g/mol), O$_2$ (32g/mol), Ar (40g/mol), H$_2$O (18g/mol) – arrange so lightest is on the left side and heaviest is on the right side of the series}

11. a. \[
\nu_{\text{rms}} = \sqrt{\frac{3RT}{M}}; \quad \nu_{\text{rms}} = \sqrt{\frac{3(8.314\text{J/mol K})(25.0+273.15\text{K})}{(16.0\text{g/mol})(1\text{kg}/1000\text{g})}} = 681.6\text{m/s}
\]

12. 177K \[
\nu_{\text{rms}} = \sqrt{\frac{3RT}{M}}; \quad 510 = \sqrt{\frac{3(8.314\text{J/mol K})T}{(17.0\text{g/mol})(1\text{kg}/1000\text{g})}}; \quad \text{square both sides: } 260,100 = \left(\frac{3(8.314\text{T})}{0.0170}\right)\text{; solve for T; T = 177.3} \]

13. 601K \[
\overline{KE} = \frac{3}{2}RT; \quad (7.50\text{kJ})(1000\text{J/1kJ}) = (1.50\text{mol})(8.314\text{J/mol K})(T); \quad \text{solve for T; T = 601.4K}
\]

14. e. {use Graham’s law: \[
\frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{M_2}{M_1}}; \quad \frac{406}{245} = \sqrt{\frac{0.044}{M_1}}; \quad 1.657 = \sqrt{\frac{0.044}{M_1}}; \quad \text{square both sides: } 2.746 = 0.044/M_1; \\
2.746M_1 = 0.044; M_1 = 0.0160\text{kg/mol x 1000g/1kg} = 16.0\text{g/mol}; \text{CH}_4 \text{ is the only molecule with this molar mass} \]

15. 6390K \[
\frac{M_1}{M_2} = \frac{T_1}{T_2}; \quad \frac{0.0440\text{kg/mol}}{0.00202\text{kg/mol}} = \frac{T_1}{20.0 + 273.15\text{K}}; \quad T_1 = \frac{(0.0440\text{kg/mol})(293.15\text{K})}{0.00202\text{kg/mol}} = 6385\text{K}
\]

16. a. 303ppm {0.0303%)/100 = 0.000303; 0.000303\[
\frac{1 \times 10^6}{1 \times 10^6} = \frac{303 \text{ parts}}{1 \text{ x 10}^6} = \frac{303 \text{ parts}}{1 \text{ x 10}^6} = 303 \text{ parts per million} = 303\text{ppm}
\]

b. 7.32 x 10$^{19}$ CH$_4$ molecules \{PV = nRT; solve for n; \[
n = \frac{PV}{RT}; \quad n = \frac{(54.2\text{torr})(1.0\text{atm})/760\text{torr})(100.0\text{L})}{(0.0821\text{L atm/mol K})(-56.5 + 273.15\text{K})}; \\
n = 0.4009\text{mol of air; convert to particles: } 0.4009\text{mol} \quad \left(\frac{6.022 \times 10^{23} \text{ particles}}{1\text{ mol}}\right) = 2.414 \times 10^{23} \text{ particles air}; \\
\text{use ppm: } 2.414 \times 10^{23} \text{ air particles} \quad \left(\frac{303 \text{ CO}_2 \text{ molecules}}{1 \times 10^6 \text{ air particles}}\right) = 7.316 \times 10^{19} \text{ CO}_2 \text{ molecules} \}

17. c. 34.3\% \{ \% \text{ increase} = \frac{\text{current amount} - \text{previous amount}}{\text{previous amount}} \times 100\%; \quad \% \text{ increase} = \frac{407 - 303}{303} \times 100\% = 34.3\% \}
17. a. \( \text{SO}_2 \) \{under the same conditions, gas with greatest molar mass has greatest D\}
b. \( \text{SO}_2 \) \{under the same conditions, 2 gases have the same number of moles; the one with the greater molar mass has the greater mass\}
c. all have the same \# molecules \{under the same conditions, 2 gases will have the same \# moles and hence the same \# molecules\}
d. all have the same average kinetic energy \{since average KE \( \propto \) T \( \rightarrow \) same T means same average KE\}
e. all have the same \# moles \{each has the same P, V, and T\}
f. \( \text{CH}_4 \) \{\( \text{CH}_4 \) is the smallest molecule and smaller molecules travel faster than larger ones at the same T\}
g. \( \text{CH}_4 \) \{\( \text{CH}_4 \) has 5 atoms/molecule and all the gases have the same \#molecules at the same P, T, and V so \( \text{CH}_4 \) has the greatest \#atoms\}

18. e \{“I”: True; kinetic energy is proportional to T and they have the same T; “II”: False; 1 mol of either gas occupies 22.4L at STP; “III”: True; pressure is a functional of \#mol; “IV”: False; Ne is larger so at the same T it travels slower; “V”: True; D = mass/V; the volume is the same (1L); since they both have the same P, V, T, they will have the same number of moles; since Ne is 10 times as heavy as \( \text{H}_2 \), it will have 10 times the mass and hence, 10 times the D; so I, III, and V are true \( \rightarrow \) “e”\}

19. a. smiling because the molar mass of the smiling gas is smaller than the molar mass of the frowning gas; hence, the smiling gas will have a greater root mean square velocity and will diffuse farther in the same amount of time and therefore reach the midpoint before the frowning gas will arrive
b. Row 9 \{using \( \frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{M_2}{M_1}} \) would yield: \( \frac{\text{smiling gas}_1}{\text{frowning gas}_2} = \sqrt{\frac{171.04}{44.02}} = \sqrt{3.886} = 1.97 \); rearranging the equation: smiling gas = 1.97(frowning gas); this means the velocity of the smiling gas = 2 x the velocity of the frowning gas; the smiling gas will therefore travel 2x faster than the frowning gas and since distance = velocity x time, the smiling gas will travel 2x as far in the same time period as the frowning gas has traveled; the diagram below shows the smiling gas moving 2 Rows (blue arrows) while the frowning gas moves just 1 Row (red arrows) in the same time frame reflecting their different velocities; they meet at Row 9\}